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EFFECTS OF VARIOUS COGNITIVE PROCESSES ON QUASI-PERIODIC PATTERNS

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Effects of Various Cognitive Processes on Quasi-Periodic Patterns

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EFFECTS OF VARIOUS COGNITIVE PROCESSES ON QUASI-PERIODIC PATTERNS

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[To the students of the Georgia Institute of Technology]

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SUMMARY

Quasi Periodic Patterns are a way of finding reoccurring patterns in brain imaging data. In this experiment, researchers were interested in examining how similar QPPs were in various cognitive processes. In order to execute this, researchers put participants in an fMRI scanner and obtain functional brain images as they conducted a 0-back task, a 2-back task, flanker task, and a resting state scan. It was hypothesized that 0-back and 2-back brain activity would be most similar, then flanker brain activity will be similar to these, and the resting state scan would not be similar to any of the tasks. In addition, it was hypothesized that the 2-back QPP will have greater correlation strength and frequency than the 0-back QPP. A cluster analysis was executed to obtain an average template for each of the conditions which was compared between each other to obtain an index of similarity. Future work should include different tasks that are dependent on other cognitive processes to see the effects on their QPPs.

CHAPTER 1

INTRODUCTION

In a world of constant demands and several tasks to execute, it is necessary to understand the underlying neural mechanisms that allow this to occur. What is particularly interesting is the brain's ability to switch between tasks requiring different cognitive processing. Task switching is a part of our everyday lives and is done without exerting excessive effort. During a day at work, we experience this when switching between remembering a colleague's name, a long term memory task, to reading and comprehending emails, a short term memory task. The brain's processing state undergoes a transition between the default mode network and the task positive mode network when such task switching takes place, but the precise neural mechanisms and functional connectivity that occur between the two networks during the transition remained unclear for decades.

In 2009, Majeed et al. examined functional connectivity using an anesthetized rat model and discovered the presence of a spatiotemporal structure that illustrates the underlying neural activity that occurs during task switching (Majeed et al., 2009). After examining waves of activity in rat brains, researchers found a specific brain wave pattern that occurred in between task switching. The brain wave pattern was only sometimes detectable, giving rise to its name as the quasi-periodic pattern (QPP). The quasi periodic pattern drew attention in the neuroscience field because it demonstrated characteristics that were identical to characteristics of known functional networks in the rat. To further examine the implications of this finding in relation to humans, quasi-periodic patterns (QPP) were closely observed using the same protocol used on rats in the previous experiment (Majeed et al., 2011). Results from the experiment confirmed the existence of QPPs in humans and demonstrated that QPPs are almost always functioning in both rats and humans (Majeed et al., 2011). However, the data obtained demonstrated the presence of identical QPPs in task performing individuals and resting individuals. To distinguish between QPPs of resting and task performing individuals, Abbas et al. observed and compared the QPPs of resting-state individuals and task performing individuals, and tracked the brain in 20 second intervals (Abbas et al., 2018). The results of the experiment demonstrated that the spatial pattern of the QPP in task-performing individuals changed throughout the trials and occurred with greater strength and frequency than resting state individuals (Abbas et al., 2018). Though the findings of the experiment were significant in proving a difference in QPP of resting and task-performing individuals, researchers failed to distinguish between short-term memory and long-term memory tasks for the task performing individuals, and used both processes to make a single conclusion (Abbas et al., 2018). In the experiment, researchers implemented a 0-back task and a 2-back task, referring to the both tasks interchangeably, without making a distinction between the fact that the 0-back task depends on long term memory processing while the 2-back task depends on working memory processing. Therefore, it is necessary to examine QPP's in task performing individuals and compare the QPP's obtained during a short-term memory task, the 2-back task, and a long term memory task, the 0-back task. In addition, the experiment conducted by Abbas et al. used very little data consisting of 8 blocks of 20 second trials for a total of 4.3e minutes of data; therefore, conclusions made by researchers may be prone to error due to insufficient data obtained. It is necessary to examine QPPs in task participating individuals versus resting state individuals using longer time intervals to ensure enough data is obtained.

In this experiment, researchers are interested in examining the effects of cognitive processes on QPPs in task- performing individuals when executing a short term memory task versus a long term memory task. Participants will be put in an fMRI machine, and will be asked to complete a 2-back task, a zero-back task, a flanker task, and a resting trial. The 2-back task is dependent on working memory processing in which the participant is required to remember a target that is presented 2 trials before, while a 0-back task depends on long-term memory processing in which a participant must remember a target that presented at the beginning of a trial. Flanker requires participants to focus on the arrow in the middle of 5 arrows and respond to the direction it points to, and relies on recall and recognition to a lesser extent. Using these various tasks will allow researchers to investigate the difference in QPP between the varying cognitive processes. Participants will execute a resting-state task, a 0-back task, and a 2-back task, and a flanker task for longer periods of time to ensure enough data is obtained. Researchers hypothesize that 0-back and 2-back brain activity will be most similar, then flanker brain activity will be similar to these, and the resting state scan will not be similar to any of the tasks since no task is being conducted. In addition, it is hypothesized that the 2-back QPP will have greater correlation strength and frequency than the 0-back QPP because the 2-back task requires more cognitive effort than the 0-back task, as concluded in Abbas et al's study conducted in 2018.

CHAPTER 2

LITERATURE REVIEW

As society progresses, there is increasing pressure for individuals to juggle several things at once both quickly and accurately. Multitasking has become such a prominent part of our everyday lives that we often engage in several activities and switch from one activity to the next without realizing how much we are balancing at once. It is important to understand the underlying mechanisms in the brain that enables this to occur. In particular, this field of study is interested in understanding more about how the brain can modulate task switching when different cognitive processes occur.

In 2009, Majeed et al. examined spatiotemporal dynamics of low frequency fluctuations in the rat cortex with the use of an anesthetized rat model. In order to do this, researchers anesthetized rats and obtained gradient-echo planar images and used power spectral analyses to detect various frequency peaks. Researchers obtained connectivity maps that indicated the presence of frequency peaks that had a specific pattern. This pattern consisted of two low frequency peaks, each with unique characteristics that kept reoccurring in the data. What was interesting about this pattern of brain activity is that it occurred each time rats switched tasks, roughly every twenty-five seconds (Majeed et al, 2009). However, the brain pattern sometimes did not occur at all. This paved the way for the name of the brain pattern, known as the quasi periodic pattern (QPP). In addition, they concluded that the second low frequency peak had waves of activity that began in the secondary somatosensory cortex and then led into the primary motor cortex (Majeed et al, 2009). The conclusions of this experiment were interesting because researchers were able to identify a brain pattern that was clearly distinguishable and occurring between task switching; however, the presence of the QPP in rats could only give us insight to the functionality of the rat brain. Therefore, it was necessary to continue this experiment on humans to see if QPP could be demonstrated by the human brain as well.

The findings in Majeed et al's experiment in 2009 began to draw attention in the neuroscience field because it demonstrated characteristics that were identical to characteristics of known functional networks in the rat. Researchers began to wonder whether or not the same brain pattern occurred during task-switching in humans as well. In 2011, Majeed et al. conducted the same experiment executed on rats except this time on humans as well. Researchers obtained spatiotemporal patterns from fMRI data, and used it on both rats and humans to characterize and compare the spatiotemporal patterns. Results of the study indicated a presence of the same quasi periodic pattern that was demonstrated in rats, occurring roughly every twenty-five seconds and sometimes not occurring at all in between tasks (Majeed et al, 2011). This experiment was especially significant because it showed that blood oxygen dependent levels fluctuated during the QPP (Majeed et al, 2011). However, the use of fMRI functional connectivity maps may have exempted some interactions that occurred, as this methodology is not strong enough to pick up on recordings that are deeper in the brain. This is a limitation of fMRI processing and data analysis, and questions the amount of information that can be obtained solely from fMRI data; however, the observation of a brain pattern that was similar to the pattern observed in rats was indicative of the existence of QPP in humans. Further investigation of the validity would need to be conducted to ensure that fMRI processing was a plausible method to obtain data illustrating the presence of QPPs.

In order to explore the affect of post-traumatic brain injuries on QPPs, researchers executed the same experiment conducted on individuals by Majeed et al in 2011, except this time using an EEG procedure and participants who had been diagnosed with post-traumatic brain disorders. Researchers found a significant difference in the degree of fluctuation in the duration of the corresponding EEG fragment between individuals before and after their brain injury. What was also significant, was that the data was consistent with the findings concluded from fMRI data (Antisperov et al, 2017). Therefore, the limitation of fMRI processing was explored and proven to be sufficient in determining the neural mechanisms associated with QPPs.

After observing the presence of QPPs in humans, it was important for researchers to understand whether one's state of activity had an effect on the QPP obtained. In 2018, Abbas et al sought to discover whether or not there was a difference between QPP's of resting state and task-performing individuals. In this experiment, researchers observed and compared the spatiotemporal QPP patterns from fMRI data of resting-state individuals and task performing individuals, tracking the brain roughly every 20 seconds to ensure the onset of QPPs were recorded (Abbas et al., 2018). The results of the experiment indicated that the QPP of task-performing individuals changed throughout the trials. In addition, they found that the QPP's in task performing individuals occurred with greater strength and frequency than in resting-state individuals (Abbas et al., 2018). This illustrated the vital role of QPPs in the connectivity of default mode and task positive networks, and gave rise to discussion regarding anti-correlation seen between the two networks. However, there were several limitations in the experimental design of the experiment that needed further examination.

Though the findings of the experiment conducted by Abbas et al were significant in demonstrating a difference in the QPP of resting and task-performing individuals, throughout the experiment, researchers omitted a distinction between short-term memory and long-term memory tasks for the task performing individuals and used both processes to make a generalized conclusion (Abbas et al., 2018). Researchers conducted a 0-back task and a 2-back task without making a distinction between the fact that the 0-back task is dependent on long term memory processing while the 2-back task is dependent on working memory. Therefore, it is necessary to conduct the same experiment but examine QPPs in task performing individuals and compare the QPPs obtained during a short-term memory task and a long term memory task. Another limitation that occurred in the experiment conducted by Abbas et al. was the use of very little data. Further experiments must be conducted with greater data through the use of time intervals longer than 20 seconds to avoid error due to an insufficient collection of data.

In this experiment, researchers are interested in examining the effects of cognitive processes on QPPs in task- performing individuals when executing various tasks. This experiment is a continuation of the experiment conducted by Abbas et al; however, it will make a distinction between short term memory tasks through the use of a 2-back task, and long term memory tasks through the use of a 0-back task. In addition, the experiment includes a The tasks used will be the same ones used in the experiment conducted by Abbas et al; however, the time intervals will be longer to ensure enough data is obtained to make conclusions about the existence of the QPP and the effects of cognitive processes on the brain wave pattern. Researchers hypothesize that 0-back and 2-back brain activity to be be most similar, then flanker brain activity will be similar to these, and the resting state scan will not be similar to any of the tasks and that the 2-back QPP will have greater correlation strength and frequency than the 0-back QPP.

CHAPTER 3

METHODS AND MATERIALS

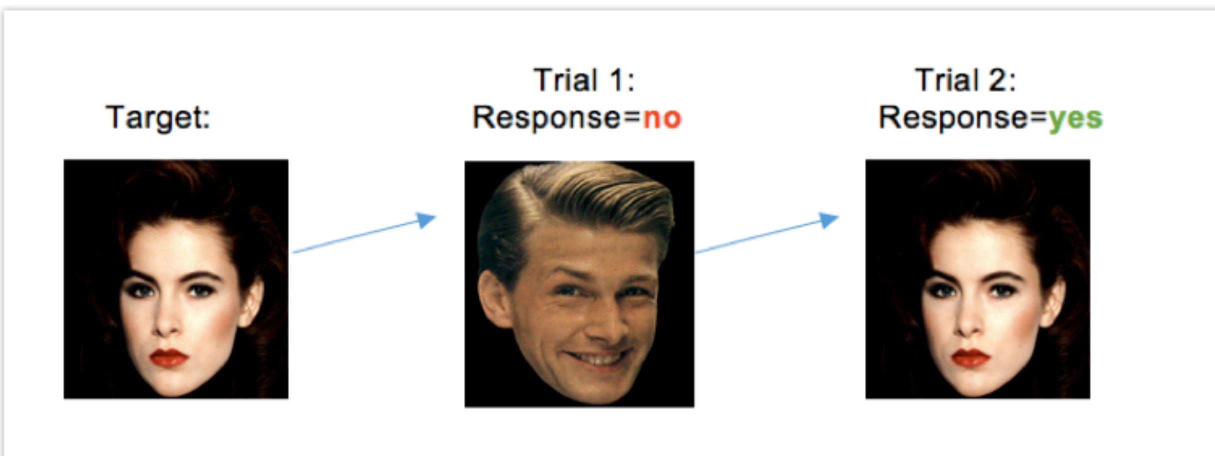
In this experiment, participants will be exposed to a functional magnetic resonance imaging (fMRI) scanner at the Center for Advanced Brain Imaging. The fMRI scanner measures small changes in the brain's magnetic fields and we use these small changes in the magnetic field to depict an image of the brain. Participants will be asked to lie still for approximately 90 minutes, and during that time, fMRI images will be obtained as they execute the various tasks. Participants are able to see the screen through a mirror mounted on the head coil. After being put in the fMRI scanner, participants will be instructed to complete a resting state scan, a 0-back task, a 2-back task, and a flanker task in random order. Each task begins with a practice block in which participants can practice the task to get an idea of what the real task will be like. During the resting state scan, BOLD (blood oxygen level dependent) signals are obtained as participants stare at a fixation cross. The 0-back task instructs participants to remember a target and press a key each time it is displayed on the screen (figure 1). If the stimuli match the target, participants are asked to hit the 'match' button on the button box and if not, they are instructed to hit the 'no match' button on the button box. A 2-back task requires participants to remember the stimuli that was presented two stimuli before, and requires a response as well (figure 2). If the stimuli matches the stimuli presented two images before, participants are asked to hit the 'match' button on the button box and if not, they are instructed to hit the 'no match' button on the button box. In the flanker task, the participant is asked to look at the middle arrow in a set of five arrows and respond whether it is directed right or left (figure 3). The stimuli are always back-projected onto the screen connected to the scanner. In each functional scan, there are 6 task blocks, each lasting 7 minutes and 2 resting state scans. The task blocks consist of 2-back working memory tasks, 0-back long-term memory tasks, and flanker tasks. The blocks are separated by the type of task to ensure distinction in data and are divided based on the four different categories used: faces, places, tools, outfits, and body parts. The stimuli presented to participants is done so via an Inquisit script and the imaging data is collected on a computer using Siemen's 3T Trio software.

In the analysis of this experiment, we are looking to compare the similarity of the 0-back condition, 2-back condition, flanker and rest. To do this, we use a MATLAB algorithm that finds reoccurring patterns in brain imaging data. The way we are able to obtain these QPPs from data is by first taking a random seed starting point. A seed is simply a starting point is a window starting at a random point in the data set. In order to analyze the data, it is necessary to have multiple seeds because the random seed chose may not produce the best results. After obtaining a random seed point, we use a window of approximately twenty seconds starting at that seed point. The brain activity in that window is then used as a reference and it is correlated with each window in the data set of the same size, resulting in a sliding window correlation. A sliding window correlation is the brain activation from each window that gets correlated with the starting seed point window. Next, the window series is applied with a correlation threshold of 0.2. Past research has shown that a threshold of 0.2 and a window of approximately twenty seconds is optimal for producing sufficient reoccurring patterns. Next, all the local maxima above threshold are obtained and the windows that correspond with these local maxima are averaged together to get a template of brain activation that is now the average template window. This process is then repeated using the average template window as it becomes the new seed point. This entire process is repeated numerous times until it eventually stops and we are left with several different average template windows.

The average template windows are ran through a cluster analysis, which is a way of finding items that are similar to each other and grouping them together. The winning template is the one that is from the biggest cluster and is closest to the centroid of the cluster. Essentially, it is the member of the cluster that is most similar to all the others in the cluster and is most representative of the different seed points.

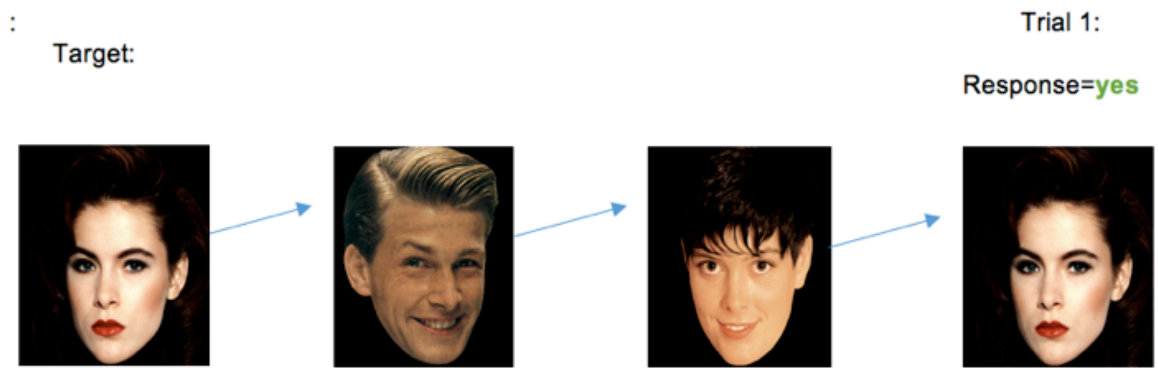
In essence, this process is a technique that allows us to observe periods of time that produce similar brain activity. The most typically found template is the one that is a pattern of brain activity that demonstrates an antagonistic relationship between the Default Mode Network and the Task Positive Network. After obtaining the average templates from the four different conditions, they are correlated to each other to get an index of similarity. The index of similarity tells us how similar they are to each other.

Figure 1. 0-Back Task During Faces Trial



*images of stimuli obtained from human connectome project (Barch et al, 2013).

Figure 2. 2-Back Task During Faces Trial



*images of stimuli obtained from human connectome project (Barch et al, 2013).

Figure 3. Sample Flanker Task

CHAPTER 4

DISCUSSION

Due to time constraints and technical issues with the script of the experiment, data was not collected. Since the experiment was a continuation of the experiment conducted by Abbas et al. in 2018, we had expected the script to be easy to code; however, we were faced with several issues. First, since we wanted to use the exact same trials and stimuli but separate the 2-back from 0-back, we faced problems trying to alter the hard engrained script. The script used in the previous experiment had blocks composed of both 0-back and 2-back tasks that went back and fourth between each other; however, in this experiment it was vital to separate the two. We thought that the script created by the HCP could be tweaked but it turned out to be difficult to alter without going through a series of problems linked in the script. Since we had expected the script to be easy to alter, we did not budget enough time to get the script running. Thus, it is essential for the next undergraduate student working on this project to budget enough time for the little things, as you never know how much time it will take to get a simple task done. In addition, we had issues linking the script to the scanner and failed to budget in time for this. If more time had been budgeted for unexpected issues, perhaps we would have gotten more done and had been able to obtain data fast enough to analyze. Future work should include more tasks that affect different cognitive processes to see what the effects of different cognitive processes are on quasi periodic patterns besides the ones tested in this experiment.

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